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XI. *Observations on Basalt, and on the Transition from the vitreous to the stony Texture, which occurs in the gradual Refrigeration of melted Basalt; with some geological Remarks. In a Letter from Gregory Watt, Esq. to the Right Hon. Charles Greville, V. P. R. S.*

Read May 10, 1804.

SIR,

Soho, April 10, 1804.

THE important geological consequences that seem deducible from the changes of texture developed by Sir JAMES HALL'S very judicious Experiments on the regulated cooling of melted Basalt, induced me to attempt a repetition of them, some time after the publication of his interesting and ingenious Paper.* I believe that formerly I had the honour of showing you some of the results of my imperfect and diminutive experiments, which only served to afford additional proofs of the transition from the vitreous to the stony texture, which takes place in the gradual refrigeration of glass. Circumstances have prevented my resuming these investigations, till it lately occurred to me that something might be learned, by exposing to the action of heat, a much larger mass of basaltic matter than, as far as I am informed, had ever at one time been subjected to experiment.

One of the common reverberatory furnaces used in iron founderies for the fusion of pig iron, was strongly heated by a fire maintained for several hours. About seven hundred weight

* Published in the Transactions of the Royal Society of Edinburgh, Vol. V.

of amorphous basalt, here called Rowley Rag, was broken into small pieces, and deposited gradually on the elevated part of the interior of the furnace, between the fire and the chimney, from whence, as it melted, it flowed into the deeper part, in which, in ordinary operations, the melted iron is collected. It was observed by the persons attending, that it did not require half the quantity of fuel, to fuse the basalt, that would have been necessary to melt an equal weight of pig iron. When the whole was melted, it formed a liquid glass, rather tenacious, from which a large ladle-full was taken, which, on being allowed to cool, retained the characters of perfect glass. The fire was maintained, though with gradual diminution, for more than six hours; after which time, the draught of the chimney was intercepted, the surface of the glass was covered with heated sand, and the furnace was filled with coals, which were consumed very slowly. It was eight days before the mass in the furnace was sufficiently cool to be extracted, and even then it retained considerable internal heat.

The form of the mass, being given by the bottom of the furnace, was considerably irregular, approaching to the shape of a wedge whose lower angles were rounded. It was nearly three feet and a half long, two feet and a half wide, about four inches thick at one end, and above eighteen inches at the other. From this diversity of thickness, and from the unequal action of the heat of the furnace, too great an irregularity had prevailed in the refrigeration of the glass, to permit its attainment of a homogeneous texture. These circumstances might probably have been counteracted by better devised precautions; but the inequality of the product is not to be regretted, since it has fortuitously disclosed some very singular peculiarities, in the

arrangement of bodies passing from a vitreous to a stony state, which might have remained unobserved, if the desired homogeneity of the result had been obtained. I shall now endeavour to describe the various products of this operation; and I shall also submit to your consideration, some remarks which appear to me to arise naturally from the phenomena I have observed; premising that, except where my opinions are supported by the unequivocal demonstration of facts, I offer them with the utmost deference to the decision of more experienced and judicious mineralogists and geologists.

It may be proper to give a concise description of rowley rag itself, before I consider the products which it yields by igneous fusion. This species of basalt is fine-grained, of a confused crystallized texture; its fracture uneven in small pieces, conchoidal in large pieces. Its hardness superior to common glass, but inferior to feldspar. Its tenacity considerable. Its action on the magnetic needle strong, but without signs of polarity. Its specific gravity, according to my trials, 2.868. Its general colour iron gray, approaching to black. It is opaque; and it reflects light from a number of brilliant points, some of which seem to be feldspar, and others hornblende.*

* “ The ragstone has been accurately analysed by Dr. WITHERING, who found
 “ that 1000 parts of it contained 475 parts of siliceous earth, 325 argillaceous earth,
 “ and 200 calx of iron; but this iron seems to me to be in a very small degree of
 “ calcination, from the dark blue colour of the stone, from the rusty colour it assumes
 “ on being exposed to a farther state of calcination by air and water, and from the
 “ magnetic property of the mountains, which, as Dr. PLOT observed, turned the needle
 “ 6° from its proper direction. This magnetic property has since been observed in
 “ several basaltic mountains, particularly in the Giant’s Causeway in Ireland, and
 “ very remarkably in a basaltic columnar mountain called Compass Hill, in the island

1st. This substance is easily fused into glass, whose texture is completely vitreous, with few air-bubbles. Its fracture undulated conchoidal. Its hardness superior to feldspar, but inferior to quartz. It possesses scarcely any action on the magnetic needle. Its colour is black : it is nearly opaque, being translucent only in very thin fragments. Its specific gravity appears to be 2.743.

2d. The tendency towards arrangement, in the particles of the fluid glass, is first developed by the formation of minute globules, which are generally nearly spherical, but sometimes elongated, and which are thickly disseminated through the mass. The colour of these globules is considerably lighter than that of the glass; they are commonly grayish-brown, sometimes inclining to chocolate brown, and, when they have been formed near the interior surface of the cavities in the glass, they project, and resemble a cluster of small seeds. Their diameter rarely exceeds a line, and seldom attains that size, as, in general, they are so near to one another, that their surfaces touch before they can acquire considerable magnitude. In the process of cooling, they adapt their form to their confined situation, fill up every interstice, and finally present a homogeneous body, wholly unlike glass, and equally unlike the parent basalt. When the union of the little globules has been imperfectly effected, the fracture of the mass indicates its structure, by numerous minute

“Cannay, one of the Hebrides, described by GEORGE DEMPSTER, Esq. in the “Transactions of the Society of Antiquaries in Scotland, Vol. I.” See Mineralogy of the South-west part of Staffordshire, by JAMES KEIR, Esq. F. R. S. published in SHAW'S History of Staffordshire, Vol. I.

Mr. KIRWAN states the specific gravity of rowley rag, which he calls *ferrilite*, at 2.748; and assigns its melting point at 98° of WEDGWOOD'S pyrometer.

conchoidal fractures, which display the form of each globule. But, if the arrangement has extended a little farther, all these subdivisions are entirely lost; the mass becomes perfectly compact, has an even or a flat conchoidal fracture, is nearly of the same hardness as the glass, is commonly of a chocolate colour, graduating into a brownish-black, and the intensity of the colour increases in proportion to the degree to which the arrangement has extended. Its aspect is rather greasy; and it much resembles some varieties of jasper, in the compactness of its texture, and in its opacity. Its magnetic action is extremely feeble. Its specific gravity appears to be 2.938.

gd. If the mass were now rapidly cooled, it is obvious that the result would be the substance I have just described; but, if the temperature adapted to the farther arrangement of its particles be continued, another change is immediately commenced, by the progress of which it acquires a more stony texture, much greater tenacity, and its colour deepens as these changes advance, till it becomes absolutely black. Sometimes this alteration is effected by a gradual transition, the limits of which cannot be assigned, but more generally by the formation of secondary spheroids, in the heart of the compact jaspideous substance. These spheroids differ essentially from those first described; the centres of their formation are more remote from each other, and their magnitude is proportionably greater, sometimes extending to a diameter of two inches, and seeming only to be limited by contact with the peripheries of other spheroids. They are radiated, with distinct fibres; sometimes the fibres resemble those of brown hæmatites, and sometimes they are fasciculated irregularly, so as to be very similar in appearance to the argillaceous iron ores rendered prismatic by torrefaction. They are

generally well defined, and easily separable from the mass they are engaged in; and often the fibres divide at equal distances from the centre, so as to detach portions of the spheroid in concentric coats. The transverse fracture of the fibres is compact and fine grained; the colour black; and the hardness somewhat inferior to that of the basaltic glass. When two of the spheroids come into contact by mutual enlargement, no intermixture of their fibres seems to take place; they appear equally impenetrable, and, as neither can penetrate, both are compressed, and their limits are defined by a plane, at which a separation readily takes place, and each of the sides is invested with a rusty colour. When several spheroids come in contact on the same level, they are formed by mutual pressure into pretty regular prisms, whose division is perfectly defined; and, when a spheroid is surrounded on all sides by others, it is compressed into an irregular polyhedron.

4th. The transition from this fibrous state to a different arrangement, seems to be very rapid; for the centre of most of the spheroids becomes compact, before they attain the diameter of half an inch. As the fibrous structure propagates itself by radiating into the unarranged mass, the compact nucleus which supplies its place gradually extends, till it finally attains the limits of the spheroids; and the same arrangement pervades the matter comprehended between them. The mass has now assumed a compact stony texture, and possesses great tenacity. Its hardness is somewhat inferior to that of the glass from which it was formed. Its action on the magnetic needle is very considerable. Its specific gravity is 2.938. Its colour is black, inclining to steel gray: it is absolutely opaque, and only reflects light from a few minute points. Though the divisions between

the spheroids are rendered imperceptible to the eye, they are not obliterated, and their rusty surfaces are often disclosed by an attempt to fracture the mass.

5th. A continuation of the temperature favourable to arrangement, speedily induces another change. The texture of the mass becomes more granular, its colour rather more gray, and the brilliant points larger and more numerous: nor is it long before these brilliant molecules arrange themselves into regular forms; and, finally, the whole mass becomes pervaded by thin crystalline laminæ, which intersect it in every direction, and form projecting crystals in the cavities. The hardness of the basis seems to continue nearly the same; but the aggregate action of the basis, and of the imbedded crystals, on the magnetic needle, is prodigiously increased. It appears to possess some polarity; and minute fragments are suspended by a magnet. Its specific gravity is somewhat increased, as it is now 2.949. The crystals contained in it, when examined by a microscope, appear to be fasciculi of slender prisms, nearly rectangular, terminated by planes perpendicular to the axis; they are extremely brilliant; their colour is greenish-black; they are harder than glass, and fusible at the blowpipe; they are suspended by the action of a magnet. They are arranged nearly side by side, but not accumulated in thickness, so that they present the appearance of broad thin laminæ; they cross one another at all angles, but always on nearly the same plane; and the lamina thus formed is often three or four lines long, and from a line to a line and a half broad, but extremely thin.*

* It may be observed, that the cavities which existed in the glass are not obliterated during the subsequent processes, though their interior surfaces undergo some change. The minute globules first formed often become prominent, and project into the cavities.

It seems obvious, that an equalized temperature would have rendered the whole similar to the substance last described; and it may be fairly inferred, that by a continuance of heat, the minute crystals would have been augmented in their dimensions, by the accession of molecules still engaged in the basis, or by the union of several crystals, till they acquired sufficient magnitude for their nature to be absolutely determined by the usual modes of investigation. It is probable, however, if such precautions had been taken as might have secured this degree of perfection in the ulterior result, that the mass would only have exhibited an uniform aspect, and that the interesting initial phenomena would not have been discovered.*

There are some considerations which appear to offer a partial explanation of the formation of the globules, and of the radiated spheroids. It is well ascertained that heat is emitted by all bodies, in their change from a gaseous to a fluid state, and also

These minute points are soon obliterated by the large curves of the fibrous spheroids, which give a mamellated form to the interiors of the cavities; and, when the crystals are generated in the mass, they shoot into some of the cavities, and line them with their brilliant laminæ.

* In this and the succeeding paragraphs, the word molecule is used in the sense assigned to it by HAUY and DOLOMIEU, and is understood to represent the peculiar solids, of definite composition and invariable form, the accumulation of which, forms the crystals of mineral substances. Such molecules, preserving their form and their essential characteristics, may be extracted from most crystals by mechanical division, and may be subdivided as far as our senses can recognise them. Though we cannot by mechanical means directly divide them into their elementary particles, we are enabled to effect this by chemical solution, the only power to which their aggregation yields. It will be evident, from the observations that follow, that I am inclined to adopt the ingenious idea of DOLOMIEU, that many apparently homogeneous rocks are compounds of the minute molecules of several species of minerals; and that, where a suitable opportunity is given, these will develop themselves by the formation of their peculiar crystals.

in their change from a fluid to a solid state. It is reasonable to suppose, that heat may also be emitted in those changes of arrangement which affect the internal texture of a body, after it has attained an apparently solid state. That a succession of such changes does actually take place, appears to me demonstrated by the appearances I have described, and by the increase of specific gravity, which seems to keep pace with the internal changes of the substance. It would appear, that these changes are caused by a gradual diminution of temperature, which permits certain laws to induce peculiar arrangements among the particles of the glass. When several of these particles enter into this new bond of association, they must form a minute point, from which heat must issue in every direction. That heat will gradually propagate itself, till the temperature of the glass is equalized; and then the recurrence of the circumstances which induced the first particles to arrange, will cause other particles to arrange also, which the attraction of aggregation will dispose round the point first formed. A second emission of heat in every direction will take place; the temperature will again be equalized; and again another concentric coat of arranged particles will apply itself to the little globule. But, at the time when the central point of this globule was formed, the equality of temperature, in the mass of glass, would probably cause a number of similar points to be generated. The formation of each must proceed in a similar manner to what I have described, till their surfaces touch, and all the glass be converted into the same substance.

These globules are therefore formed of concentric coats, but they are also radiated. Every one must have remarked the connexion that almost uniformly exists, between the radiated

structure and the formation by concentric coats. There are few radiated substances which are not divisible into concentric fragments; and as few concentric arrangements which are not radiated. Of the first, it may be sufficient to mention hæmatites; of the second, calcareous stalactites. The tendency to this union of structure, may perhaps be produced by the radiation of the emitted heat, or moisture, if the solution be aqueous; and the divisions of the coats will naturally take place at those pauses in the accumulation of particles, which the momentary emission of heat necessarily induced.

If this be allowed to explain the formation of the first series of globules which consolidate into the jaspideous substance, it will also explain the formation of the larger and more distinctly radiated spheroids, which have been already stated to be very easily divisible into concentric fragments. They probably were also formed round a central point, by the accumulation of thin coats; and the tendency to radiation, which seems almost inseparable from this structure, was perhaps aided by the arrangement induced by the emission of heat from every part of the surface of the spheroids. This mode of formation has the advantage of explaining their impenetrability. Had they been generated by radii diverging from a centre, their compactness must have diminished as their diameter increased; but, in the structure which I have supposed, each coat is composed of particles solidly arranged in immediate contact with each other, leaving no spaces for penetration. The same progress is rigidly observed in the extension of the compact nucleus, which always occupies the centre of the radiated spheroids, and finally extends to their peripheries. It observes the concentric divisions of the radiated part with the greatest precision; and the line of their

separation is always perfectly defined. But the state of aggregation into which the substance has now entered, is so perfect as to overcome the operation of the causes which formerly induced the fibrous structure, and the mass remains compact. The only change that the substance afterwards undergoes, consists in the gradual accumulation of the crystalline molecules, and their arrangement, by their individual polarity, into regular solids. This depends on very different laws from those which consolidated the fluid glass, and aggregated its particles into a compact uniform stone.*

The appearances that I have endeavoured to describe, seem deserving of consideration in several points of view. Few things can be more at variance with commonly received opinion, than the diversified succession of changes of structure which this glass exhibits in its passage to a crystallized state. The generation of the globules which unite to form the jaspideous substance, is what we might be prepared to expect, by observing the cooling

* The case is considerably different, where crystals possessing regular forms are generated in glass. The molecules of which they are formed, have doubtless been only suspended in the vitreous medium; and their union is determined by crystalline polarity, which appears to me perfectly distinct from the simple aggregation which changes a fluid into a solid, whether it be homogeneous or compound, which affects the internal arrangement of those bodies, but which never can separate their components into distinct masses, or form them into regular solids. Every molecule, at the moment of its formation, must necessarily be endowed with all the properties it afterwards possesses. The suspension of such molecules in a fluid medium, though it may conceal, cannot alter those properties; and the union of such molecules, to form a regular solid, in no respect alters their individual or aggregate qualities. Whether heat be evolved at the moment of this union, is a question not easily solved; as the crystallizations with which we are familiar are from chemical solutions, in which some of the molecules are generated by the separation of a combined substance, at the moment when others are united by crystalline polarity.

of a common iron furnace flag. But it appears not very obvious to common apprehension, that the species of arrangement requisite to form this intermediary substance, could be compatible with any fluidity permitting farther motion of the molecules of the mass; yet, immediately after the completion of this arrangement, they receive a new disposition, and the radiated fibrous structure commences. Sometimes this pervades even the unaltered glass; but I presume this only to happen where the minute globules first formed were scattered so far asunder, that their centres became fibrous, before their peripheries came into contact. This view of the subject is justified by the analogous operation of the formation of crystals, similar to those described, in the heart of the radiated spheroids, while their exteriors still retained the fibrous texture.

If it be considered as extraordinary, that a change should be effected, converting an apparently solid and homogeneous mass into an accumulation of radiated spheroids, and that these radii should lose their fibrous structure, and assume the texture, aspect, and tenacity, of a compact, hard, and homogeneous stone, it is certainly much more extraordinary, that this stone should permit farther arrangement to proceed, and should enable the crystalline molecules which it contains in a state of confused aggregation, to arrange themselves, and to form crystals, which, although minute, are equal in the perfection of their forms, and in the brilliancy of their natural polish, to the most precious products of crystallization. It is also well deserving of observation, by how regular a march the magnetic influence of the substance keeps pace with the perfection of its arrangement, till it becomes so powerful, that fragments of the regenerated stone are suspended by the attraction of a magnet.

It has been most justly remarked by Mr. SMITHSON, that solution, far from being necessary to crystallization, effectually prevents its commencement; for, while solution subsists, crystallization cannot take place. It may remain a question, whether previous solution be essential, as a preparatory means of obtaining, by subsequent evaporation, or cooling, the small parts of bodies disengaged, so that they may unite to form regular crystals. If by solution be only meant, that simple action of heat, or water, which merely counteracts the force of aggregation, and relieves the molecules from their bond of union with each other, it certainly is a requisite; but if by solution be meant, that action of affinities by which not only the force of aggregation is overcome, but the combinations which constitute the molecules are destroyed, it obviously is not only unnecessary, but prejudicial to crystallization; as a new set of molecules must be formed, by a new combination of the elementary particles, before the formation of regular bodies can commence. The suspension of the molecules ready to crystallize, may be correctly said to be merely mechanical. Though the mechanical action of trituration can never be expected to resolve even the most easily divisible body into its molecules, because the fractures will be at least as frequently across the natural joints as in their direction, yet, even by this rude method, some perfect molecules may be disengaged; for we find, that water passing over large surfaces of siliceous sand, finds some molecules of silex in the state proper for aggregation, and even for crystallization. Mechanical suspension in a fluid medium, of such density that the crystalline polarity may be enabled to counteract the power of gravity, is with justice considered by Mr. SMITHSON

the only requisite for the formation of crystals.* The circumstances I have detailed, appear to me an additional confirmation of this remark, and perhaps go still farther, by showing that even the fluidity (in the common sense of the word) of the suspending medium is not an indispensable condition. For it appears impossible to annex the idea of fluidity to the union of the minute globules which form the jaspideous substance, still less to that substance when formed, and still less to those spheroids whose obstinate impenetrability is so strongly defined. And if, by any power of imagination, these can be supposed to be fluid at the time they retain this conformation, how can it be supposed that the compact hard tenacious stone into which they are changed could retain these characters in a fluid state? Yet the subsequent formation of crystals proves, that either all these contradictions must be, or that the particles of bodies apparently solid must be capable of some internal motion, enabling them to arrange themselves according to polarity, while they are solid and fixed, as far as they have reference to the ordinary characters of fluidity.

Instances even more remarkable have very long been known and authenticated, though perhaps they have not been generally regarded with the attention they deserve. Glass vessels are well known to be convertible into REAUMUR's porcelain, by the internal arrangement of their particles, without losing their external form, and consequently at a temperature very much below that requisite for their fusion. The change of glass into

* See a chemical Analysis of some Calamines, by JAMES SMITHSON, Esq. *Philosophical Transactions* for 1803, page 27. See also DOLOMIEU, *Journal des Mines*. No. 22, page 53.

REAUMUR's porcelain, does not arise from an evaporation of the alkali, as has been alleged, but from a regular arrangement of the molecules of the glass. It commences by the formation of fibres perpendicular to the surface of the glass, and penetrating into it. At nearly the same time, small radiated globules are formed in the interior of the glass, and the union of these with the fibres, by their mutual increase, forms the whole into a new substance; and, if the requisite temperature be longer maintained, the fibres disappear, and the whole becomes fine-grained, and almost compact. This substance, from the improved state of its aggregation, is much stronger and more tenacious than before, and is not fusible at a heat sufficient to fuse the glass it was formed from; but, if that aggregation be once destroyed, the glass resulting from its fusion is equally fusible with the original glass; and a repetition of the process will again form REAUMUR's porcelain, which may be again fused, and so on repeatedly, for the quantity of alkali evaporated during the operation is extremely small. The hardness and brittleness of metals rapidly cooled, contrasted with the softness and tenacity resulting from their gradual refrigeration, are all analogous instances; and all the processes in which annealing is employed, and more remarkably the tempering of steel, are proofs of the internal motions and arrangements of the particles of matter, at temperatures very much below the heat requisite for their fluidity.

Whatever doubts may arise respecting the formation of the crystals, there seems no reason to suppose that their gradual increase would cease, till all the molecules belonging to that species were exhausted, if the temperature favourable to their generation was continued. If the mass was entirely composed

of one species of molecules, it would be resolved into an aggregation of crystals of the same substance; and probably, by a still farther continuation of the process of arrangement, into one crystal, which, though it might not possess a regular external form, would be perfect in its internal structure.

But, if the mass contains two distinct species of molecules, different results must take place, which will be modified by the proportional quantities of the components. As it has been demonstrated by BERTHOLLET, that the attraction of masses of matter are relatively as their quantities, it follows, that unless a very potent counteracting cause be exerted, the most abundant ingredient in the mixture will be the first to crystallize. But this crystallization will not comprehend the whole of its molecules; for, after a certain quantity of them are arranged, the proportions of the remaining fluid are altered; that ingredient which was before the least, may now be equal, or even greatest, and it will exercise its attraction. As the first crystallization, by subtracting a large portion of the fluid particles, must have obliged the molecules of the less abundant substance to approach each other very closely, they may be able to collect themselves entirely in their first attempt to crystallize, or they may form alternate crystallizations with the remaining unarranged molecules of the more abundant substance. However various the species of molecules may be, they will be regulated by analogous laws, and only serve to diversify the generated substances.

It by no means follows, that the crystals afterwards found to be most infusible would be first generated. Their formation does not altogether depend on their greater or less fusibility, but on the relative strength of the attraction which unites them to the matter they are immersed in, and of the polarity which

invites them to crystallize. In all crystallization from compound fluids, the order in which the several bodies crystallize must be determined by their relative quantities and attractions. It is perfectly obvious, that no molecules can form a crystal in a heat sufficient for its fusion; but it by no means ensues, that it will be formed as soon as the molecules are cooled to the point where the crystalline polarity overcomes the disintegrating power of heat; for they may remain suspended in a fluid formed by more fusible bodies, provided this fluid be sufficiently abundant to keep them from contact with each other, for the crystalline polarity appears to exert itself only at extremely small distances. In a mass composed of substances in a state of fluidity, with refractory molecules suspended among them, it is pretty clear, from the preceding paragraph, that the most abundant ingredient will be the first to crystallize. But the removal of a portion of the suspending fluid must bring the refractory molecules nearer together, and perhaps so near that the crystalline polarity may overcome the attraction of the fluid for them; they will therefore crystallize next, and will be followed by the remaining ingredients, in the order their attractions dictate.

As the crystals last formed must necessarily be impressed, at the parts in contact, by the peculiar forms of those which have been first generated, it also follows, if the preceding reasoning be just, that the infusible crystals may be found impressed by the more fusible substance, which crystallized first; and the remaining ingredients of the mixture, which were subsequently arranged, may be moulded on the refractory crystals; and thus, in the same specimen may exist, a refractory substance generated by fire, impressed by more fusible bodies, and impressing

them in its turn. From the same consideration it is obvious, that no crystal can be formed at a temperature above the degree of its fusibility; and that, as a necessary consequence, no crystal which is more fusible than the basis in which it is imbedded, can be formed by igneous operation.

The same laws must regulate the arrangement of aqueous solutions, and of molecules suspended in aqueous solutions. All these are dependant on heat; for we are unacquainted with any fluidity, and consequently with any solution, which heat does not produce. Ice and soda have no more action on each other than soda and quartz: raise the temperature of the ice, and it unites with the soda; raise the temperature of the soda, and it unites with the quartz. Both solutions are effected by heat, of the degrees of which we know neither the beginning nor the end, and are therefore utterly unable to estimate what aliquot part of its scale is adequate to the production of these effects. Probably a very minute one.

A curious diversity may prevail in the products of a compound body subjected to fusion, when absolute solution is produced. When merely simple fusion takes place, the aggregation of the parts only is destroyed: the fluidity arises from the facility with which they move on each other; and a regulated diminution of temperature, by facilitating their reunion, can hardly fail to recompose the same species that formerly appeared to exist in the compound. But, if the molecules have been dissolved and decomposed, and their component particles diffused through the fluid, there seems to be very little probability that any reunion should compose the same molecules. It is more likely that new compounds will be formed, from which new molecules, and of course new crystals, will be generated; and

that, consequently, the same rock may become the parent of very diversified offspring. These will however retain some traces of their origin ; for, as there can be no fusion of a compound body imagined, in which the mutual action of the components will not decompose some portion, there can be no solution supposed so perfect that every molecule shall be destroyed. In the first case, there will exist the germs of a new composition ; and, in the second, there will remain the relics of the old.

If these observations are correct, considerable utility seems derivable from them, in the explanation of some geological problems. It will appear, that they strikingly illustrate the analogy which exists between the aqueous and igneous formations, and show that precisely the same order and kind of arrangement is followed, in the generation of stony masses from water as from fire ; for, the change of structure, which I have observed to be the most inexplicable part of the process by which glass passes into stone, is almost exactly imitated in the formation of calcareous stalactites. Successive depositions of calcareous carbonate, form a stalactite which at first is fibrous. A continuance of the process causes the fibrous structure to disappear, and the stalactite becomes irregularly spathose. The irregularities then vanish, and it becomes perfect calcareous spar, divisible into large rhomboids, with the form peculiar to that mineral ; and all the gradations may be found in the same specimen. Nor is this change confined to a few solitary specimens ; for, a considerable extent of coast near Sunderland, is formed of a limestone composed of radiated spheroids, from half an inch to three inches diameter, imperfectly united. When one of these spheroids attains something more than the usual magnitude, it becomes compact in the heart ; and it is not unusual to discover portions of the rock,

in which the radii have entirely disappeared, and the whole mass has become compact. It is probable that the entire formation of oolithi and pisolithi is owing to the same cause; and that they are prevented from ever arriving at great size, by the union of their surfaces, and their subsequent consolidation into compact limestone, into which they are continually found to graduate.

Hitherto, I have selected instances from substances which have an undisputed claim to an aqueous origin. I shall now, on the authority of DOLOMIEU, instance a similar arrangement, in a substance respecting the origin of which theorists are not agreed. A species of petrosilex is found in the Val de Nido, in Corsica, which contains radiated petrosiliceous glands, from half a line to an inch in diameter. These glands only differ from the basis by their radiated structure, and their colour; and appear to indicate very clearly, that the rock was subjected to a species of arrangement which, if it had been completed, would have changed its nature, and probably would have rendered it porphyritic; for DOLOMIEU observes, that the centre of the glands was often occupied by a small crystal of feldspar.* The extraordinary rock called the globular Granite of Corsica, is an analogous instance. It is composed of crystals of hornblende, feldspar, quartz, and mica, in confused aggregation; and in this basis are immersed spheroids, about an inch and a half or two inches in diameter, composed of concentric alternate coats of quartz and hornblende. The centre is principally occupied by hornblende; this is surrounded by a zone of quartz. These spheroids are radiated to the centre. There can be little doubt that this rock is merely the result of interrupted crystallization; and that, if the process of arrangement had continued, this structure

* DOLOMIEU. *Journal de Physique*, 1794, page 260.

would have disappeared, and the whole rock would have resembled the present basis. Hitherto, this very singular rock has only been found in detached fragments.*

The admission that solution is not a requisite of crystallization, appears to me an important concession in favour of the aqueous system, which has laboured under very great embarrassment, from the difficulty of dissolving quartz. If a very perfect mechanical suspension be all that is requisite, we may cease to wonder at the almost daily formation of petrified wood, (in which, though crystallization does not actually take place, a very perfect arrangement is indicated, by the intimate union of the siliceous particles,) or of hydrophanous semi-opals in the decomposed serpentine of Mussinet, near Turin, or of chalcedony containing drops of water, in the decomposed basalt of Vicenza.

* I shall venture to quote another instance, on the authority of Professor PLAYFAIR.
“ The salt rock in Cheshire, which lies in thick beds, interposed between strata of an
“ argillaceous or marly stone, and is itself mixed with a considerable portion of the
“ same earth, exhibits a very great peculiarity in its structure. Though it forms a
“ mass extremely compact, the salt is found to be arranged in round masses, of five or
“ six feet in diameter, not truly spherical, but each compressed by those that surround
“ it, so as to have the shape of an irregular polyhedron; these are formed of concentric
“ coats, distinguishable from each other by their colour, that is, probably, by the
“ greater or less quantity of earth which they contain; so that the roof of the mine, as
“ it exhibits a horizontal section of them, is divided into polygonal figures, each with
“ a multitude of polygons without it, having altogether no inconsiderable resemblance
“ to a mosaic pavement. In the triangular spaces without the polygons, the salt is in
“ coats, parallel to the sides of the polygons.” Illustration of the HUTTONIAN
Theory, page 37.

I am informed, that the siliceous deposition at Geyser, is at first a porous friable mass, and that the addition of more molecules renders it fibrous; also that, on a farther addition, the fibrous structure disappears, and the whole assumes the compact even texture of chalcedony or flint. If I am not misinformed, a series of specimens illustrating this transition, existed in the cabinet of the late Dr. HUTTON, of Edinburgh.

I have endeavoured to show, that in the crystallizations resulting from igneous fusion, it is not only possible but probable, that the most infusible substances might not be the first to crystallize; and this appears to involve important consequences, for it partly removes one of the greatest difficulties that embarrasses the igneous theory, by explaining the possibility of refractory substances generated by fire being impressed by the forms of more fusible ones. It seems, however, that the same order of arrangement would prevail in substances that were suspended in a fluid medium, as the degrees of attraction would be the same. In either case, the first step by which the arrangement of an apparently homogeneous mass commenced, would probably be the accumulation of particular molecules into little globules. Such seems to have happened in variolites, and other rocks which contain spherical concretions of a different nature from their basis. Still farther advanced is the arrangement of porphyries: the molecules of one species have assumed a regular crystalline form; and sometimes two or even more varieties of crystals are formed, which remain unmixed in the unarranged basis. If the remaining molecules of that basis are susceptible of crystallization, it may be fairly concluded, that an extension of the process of arrangement would convert the porphyry into granite, or at least into one of the compound aggregates of crystals which constitute the numerous tribes of granites, grünteins, and sienites; and it seems equally probable that this might be accomplished, whether the molecules were indebted to a suitable temperature, or to an aqueous medium, for the requisite facility of movement.

The formation of granite and other rocks, must however be referred to the ultimate perfection of crystallization, by which

all the molecules have been permitted to arrange. Those granites called porphyritic, in which large crystals of feldspar are imbedded in a basis compounded of the ordinary ingredients of granite in small grains, are apparently generated from a menstruum in which the molecules of one species, being greatly predominant in number to the rest, are the first to exercise their polarity, and constitute large crystals, which are afterwards surrounded by smaller ones, resulting from the successive separations of the remaining elementary molecules.

The changes of the substance that led to the foregoing remarks, serve to show that they are not altogether hypothetical; and any proof that may appear deficient, seems to be provided by the phenomena exhibited by lavas, in which may be observed every step of the passage from the vitreous to the stony, from that to the porphyritic, and finally to the granitic state. The lava of Lipari, which passes from glass to lava, by the generation of minute globules, may be cited, on the authority of SPALLANZANI, as an instance of the commencement of the process of arrangement,* and, were not their origin still disputed, I might also cite the pitchstone lavas of the Euganean hills. It would

* SPALLANZANI, *Viaggi alle due Sicilie. Tomo Secondo*, page 238. The whole passage, literally translated, stands thus. “ This lava has a basis of feldspar, of a fine
 “ and compact grain, a splintery fracture, rough to the touch, and emitting sparks,
 “ like flint, when struck with steel. It has an ash colour, in some places approaching
 “ to a leaden colour. It is thickly filled with an immensity of little bodies, which
 “ would be distinguished with difficulty, from the resemblance of their colour to that
 “ of their basis, were it not for their globular form. But this lava is joined to a great
 “ mass of glass, which forms a whole with it, without any division or separation
 “ between them; and this lava, which in many places retains its own nature, is in
 “ many other places reduced to glass. Some parts of this glass are filled with the
 “ same little bodies, but other parts are pure glass. This is in general very compact,
 “ has a dead black colour, and breaks rather into irregular pieces than into undulated

appear, that the transition from the stony to the porphyritic state is rapid, for perfectly homogeneous lavas are among the rarest of volcanic products. The porphyritic lavas are most numerous; and it is needless to detail the varieties they present. But, though the process of arrangement has often only advanced thus far, it has in many instances proceeded much farther, and it is by no means unusual to find the entire basis regularly arranged into crystalline bodies; thus, to cite a well known instance, in many of the ancient lavas of Somma, large augites are imbedded in a crystalline mass, formed of minute crystals of leucite, together with another crystalline substance, whose nature is not perfectly determined.

The casual occurrence of volcanic glass is nowise at variance with this account, as it is sufficiently probable, that some glasses may have a much greater tendency to crystalline arrangement than others possess; and it cannot appear extraordinary, that regular crystals should sometimes be generated, even in the glass, as it is a matter of daily occurrence in artificial glasses, and in furnace slags.

If the distinction attempted to be shown between igneous fusion and solution be established, it may offer a means of accounting for the abundance of peculiar bodies in lava, which do not exist in other situations, or at least are of extremely rare occurrence. For, if the igneous action decomposes the molecules of the substances on which it operates, there seems every

“ fragments, as glass properly does. Besides, it has I know not what of unctuousity to
“ the touch, and to the eye, which is not perceptible in the more perfect volcanic
“ glasses. It yields sparks with steel, like the lava; but the lava is wholly opaque, and
“ the glass, at the angles and thin edges, has considerable transparency. It is only
“ opaque where the globules are, which appear to be particles of lava.”

probability that new compounds may result, dissimilar to any substances we are acquainted with. It would appear, that the necessity of imagining an undiscovered stratum abounding in leucites, chrysolites, and augites, may be dispensed with; and, as I have endeavoured to show the probability that the most infusible substances will not be the first to crystallize, the penetration of refractory leucites by fusible augites, will cease to be an argument against both being generated in the lava. I may also observe, that the same causes which vary the crystallized bodies resulting from igneous solution, must operate upon the unarranged basis; and that the same rock may be fused into lavas extremely dissimilar, as their varieties must depend on the degree of solution which the fusion has accomplished.*

If the analogy attempted to be shown between the aqueous and igneous formation appear founded, the transition from glass to stone can no way affect the great question which has so long divided geologists, about the origin of basalt; for, though it is synthetically demonstrated that basalt may be formed by fire, the converse of that proposition stands supported by strong analogical arguments, and its formation by water must be allowed to be at least equally possible. How far the probabilities derived from the examination of basaltic formations may influence the ultimate decision, is an enquiry in which I shall not now engage; though I cannot avoid recalling to my mind, the numerous

* The evidence of the generation of leucites in the lava which contains them, collected by LEOPOLD de BUCH, and BREISLAC, and finally acquiesced in by DOLOMIEU, appears so satisfactory, that it can hardly be deemed presumptuous to assume the point as determined. Neither de BUCH nor DOLOMIEU have been able to convince themselves that the augites were also formed in the lava; but I confess myself entirely unable to appreciate the cogency of their arguments, which seem annihilated by the admission they have made in favour of leucites.

instances of petrifications found in basalt, and, as a counterpoise to that observation, the equally numerous instances in which the heat emanating from it appears to have indurated strata, and coaked beds of coal. One remark may be stated here with propriety, as it arises immediately from the experiment which has occasioned these observations. In the ultimate result of that experiment, the arrangement of the molecules was much more perfect than in the original rock. It might be supposed, that a longer continuance of the suitable temperature was afforded it. This, however, could not be, for the mass was only a few feet long, and a few inches thick; the fire was only maintained a day; and the whole was cooled in a week. But the hill of solid basalt, from which the substance operated upon was taken, is several miles long, and several hundred feet high; and, supposing it to have been irrupted in a state of igneous fusion, it must have required months, nay years, for its refrigeration. How then comes it, that the process of crystallization is so little advanced? How comes the confusion of its texture to indicate the very reverse of the tranquillity and perfection of arrangement, which may be fairly assumed as necessarily attending the extremely gradual changes of so immense a mass?

This objection admits of being obviated, upon the supposition that, in the process of melting, the molecules of the basalt were decomposed; and that the new ones generated were more disposed to crystallize than those whose place they supplied. This explanation is in some degree justified, by the total disappearance of the minute feldspars and hornblende of the basalt; instead of which, the regenerated stone contains thin laminæ of crystals, which are probably augites.

I cannot leave this subject without noticing some particulars,

in which the process of arrangement described in the early part of this Letter, appears to yield a probable explanation of some of the peculiarities of basalt. The general disposition of basalt to divide into globular masses, in decomposing, is too remarkable a fact to have escaped the attention of naturalists; though, as far as I am informed, no satisfactory explication of it has been given. The common effects of decomposition are obviously inadequate; for it is common to see a large block of amorphous basalt separate into numerous balls, after a few months or years exposure to the weather; and, rapid as the process of decomposition has been in the intervening portions, these balls resist its farther progress with uncommon obstinacy. May not this be attributed to the formation of the radiated spheroids, whose occurrence in my experiment I have already mentioned? and may not their greater resistance of weather simply arise from their aggregation being more perfect than that of the incoherent molecules which have filled the intervals between them? Though the radiated structure has disappeared to the eye, these portions of the stone retain the superiority of more perfect internal arrangement; and, if my pigmy experiments could yield spheroids of two inches diameter, there can be no difficulty in supposing that the grand operations of nature may produce them of several feet. The separation of the decomposed fragments in concentric coats, seems easily explained; for I have already pointed out the facility with which the radii of the spheroids separated at nearly the same distances from their centres, and the form of the fragments which resulted, resembling fragments of bombs.*

* Even granite has been frequently observed to affect globular decomposition, and division into fragments of concentric coats. This mode of decomposition extends to

If this idea be not considered as entirely divested of plausibility, I may venture to extend the same principle, to account for the wonderful regularity of the prismatic configuration of basaltic columns, and also for their articulations. If we suppose that a mass of fluid basalt has filled a valley to an indefinite depth and extent, the process of arrangement in its particles must be induced by the removal of its heat or moisture, according as its solution is igneous or aqueous. This can only be done by the action of the atmosphere on its upper surface, and by the ground on which it reposes absorbing the heat or moisture from its under surface. From the variations of the atmosphere, its action must be irregular; and, from the perpetual change of the parts in contact with the heated or moist surface, its operations will always be nearly as active as at first, allowance being made for its variations. But the absorption of the ground will be regular, and regularly diminishing in activity, in proportion as the parts near the mass approach nearer to the same temperature, or same moisture, with the mass above; and its absorptions can only be carried on by its transmission of heat or moisture to the solid rocks below. From these considerations it seems evident, that the arrangement of the part of the basalt near the ground, will be begun with more energy than it can be continued, and that the results will be more slow and regular than the arrangement induced by the perpetual though variable action of the atmosphere. After the first stage in the process of arrangement has been performed, and a stratum, if I may so term it, of the jaspideous substance extended over the surface of the ground, there seems no reason to doubt

so many substances, that WERNER has called the formation it seems to indicate "*abgesonderie stücke*," which has been rendered in English *distinct concretions*.

that a number of radiated spheroids would be generated in it, which would probably have all their centres about the same distance from the ground; and, as the arranging power undergoes a gradual diminution of energy, it is not probable that two rows in height of them should be formed at once, as that would indicate a hasty process, which had prepared a greater mass of matter for their almost simultaneous formation. From these considerations, there seems no improbability in supposing, that in the arrangement of a mass of fluid basalt, a single layer of radiated spheroids would be formed, reposing on the ground which supported the mass.

I have already stated, that when the radii of two spheroids came into contact, no penetration ensued, but the two bodies became mutually compressed, and separated by a plane, well defined, and invested with a rusty colour. I also stated, that when several spheroids encountered, they formed one another into prisms with well defined angles. In a stratum composed of an indefinite number in superficial extent, but only one in height, of impenetrable spheroids, with nearly equidistant centres, if their peripheries should come in contact on the same plane, it seems obvious that their mutual action would form them into hexagons; and, if these were resisted below, and there was no opposing cause above them, it seems equally clear, that they would extend their dimensions upwards, and thus form hexagonal prisms, whose length might be indefinitely greater than their diameters. The farther the extremities of the radii were removed from the centre, the nearer would be their approach to parallelism; and the structure would be finally propagated by nearly parallel fibres, still keeping within the limits of the hexagonal prism with which their incipient formation commenced;

and the prisms might thus shoot to an indefinite length into the undisturbed central mass of the fluid, till their structure was deranged by the superior influence of a counteracting cause, which would be provided by the action of the atmosphere on the upper surface of the basalt. If this arrangement existed, the same cause that determined the concentric fractures of the fibres of the spheroids, would produce convex articulations in the lower joints of the prisms; and, in proportion as the centre from which they were generated became more remote, the articulations would approximate to planes. If the generating centres were not equidistant, the forms of the pillars would be irregular; and the irregularity would be in proportion to the diversity of distance between the centres. If the difference was great, the number of sides would be altered, and they might be found pentagonal, tetrahedral, and trihedral. As the compression of the fibres would be greatest in the level of the generating centres, the lower part of the prisms would be most compact.

All these conditions seem to be fulfilled, in the actual conformation of basaltic columns; for, in every instance I am acquainted with, they appear to have been formed in the tranquil bosom of the mass, as they have been originally masked by amorphous trap, and their prismatic structure is only displayed by the removal of this covering. This has been variously effected, sometimes by the apparent disrapture of rocks, sometimes by the exterior portions of the mass being thrown down by the failure of the ground on which it stood, sometimes by the violence of the waves, and not unfrequently by the working of quarries. In most instances, these operations have only removed the covering from one side of the colonnade; and it remains crowned, and generally surrounded, by an immense amorphous mass.

Where there are two ranges of columns, with an intervening amorphous stratum, it is probable that the upper is the result of a second inundation of fluid basalt. It is well known that basaltic columns are most solid at the bottom; and their convex articulations have been repeatedly observed. Since these considerations occurred to me, I have had no opportunity of examining, whether the divisions approach nearer to the plane surfaces as they recede from the centre from which the prism was generated, nor whether below that centre the convex surface of the articulations is inverted; but I think it by no means improbable, that subsequent observations may establish this to be the case, and thus confer on this hypothesis nearly all the demonstration of which it is susceptible. I may however add, that the phenomena of prismatic division in basaltic veins, perfectly coincide with what might be inferred from the data upon which my reasoning has proceeded. In veins, it is obvious that the refrigerating or absorbing cause must operate with nearly equal force on each side of the vein; and it follows, that two sets of prisms would be generated, which would be horizontal instead of perpendicular, and that, unless a mass of amorphous basalt was interposed between them, they must form a division in the middle of the vein, as, from the mutual impenetrability of their fibres, they could not incorporate. The coincidence of the existing phenomena with these conclusions, is sufficiently remarkable; for, in numerous observations I have made on the basaltic veins which affect the prismatic configuration, I found the prisms were always horizontal, and often, that there were two ranges of them. One of their ends applied to the wall of the veins, the other frequently united to an amorphous mass which separated them; and, when no such

intermedium occurred, there was invariably a division in the middle of the vein. Not unfrequently, the veins contain three sets of prisms; a range of small ones on each side, and of much larger ones in the middle. In this case, the little prisms are always separated from the large ones, and the divisions of the large ones are very irregular.*

After the statement of my opinion, that perfect similarity of structure may exist in the products of aqueous and igneous formation, it will hardly be necessary to conclude these observations with remarking, that I should not consider the establishment of these peculiar modes of arrangement as the slightest demonstration of the igneous origin of basalt. It appears to me, that the truth of my deductions is entirely independent of either theory, and that, if ever the period should arrive when the origin of basalt shall be determined by irrefragable demonstration, the inferences I have drawn may be accommodated with equal facility to either mode of agency.†

* The observations alluded to were made during the course of last summer, (1803,) on the very numerous basalt veins, or, as they are there called, Whin Dykes, which traverse the red sandstone and red sandstone breccia, which forms the greatest part of the coast of the Firth of Clyde, between Greenock and the Largs.

† Mr. KEIR, in his Paper on the Crystallizations formed in Glass, suggests the probability of basaltic pillars being formed by the crystallization of vitreous lavas. See *Philosophical Transactions* for 1776, Vol. LXVI. page 530.

DOLOMIEU was of opinion, that the prismatic form was peculiar to lavas which had flowed into the sea; and he attributed it to the shrinking of the mass: his description of the appearances exhibited by what he calls the prismatic lavas at the foot of Etna, merits quotation.

“ In the lavas of Etna, the form and dimensions of the columns vary as much as
 “ the manner in which they are grouped; hexaedral and pentaedral prisms are most
 “ abundant; then the tetraedral, the triedral, heptaedral, and octaedral. The least I
 “ have seen are only four inches diameter; others are more than three feet; they are

The immense magnitude of some basaltic columns, the extreme regularity of their prismatic configuration, and the peculiar structure of their articulations, have directed the attention of naturalists to them, much more than to any of the other rocks which affect the columnar form. Yet many of these are sufficiently remarkable to deserve more particular notice than has generally been paid to them; and they afford most illustrative proof, that this configuration is not confined to either the aqueous or igneous formation; for some lavas, universally allowed to

“commonly of a single shoot, which is sometimes 60 feet high; others are divided by articulations, which are from one to six feet asunder.

“I have more than once observed a large column divide into several smaller in its upper part. The columns are generally larger near the top than the bottom of the stream of lava, because they subdivide; and they are always least in that part of the stream of lava which first entered the water, the refrigeration being more prompt, and its effects more marked. Sometimes the columns are placed perpendicularly side by side, and form vertical walls, which are sometimes more than 100 feet high, and a league long; sometimes they are heaped obliquely, horizontally, and in all positions. Some, without being divided in their length, are larger at one end than the other; and then they are arranged like wood piled up, with all the small ends at one side; sometimes they are formed into pyramidal bundles, by parting from a common centre; and, finally, there are some which, by their reunion, form large balls. These radii of lava, which are rather pyramidal than prismatic, resemble those of the globular pyrites, striated from the centre to the circumference, which are found in the chalk of Champagne.

“On the shore of la Trezza, near the Mole, there is a very curious group of little articulated prisms, which issue from a common centre, and form fasciculi singularly twisted. The articulations are marked, but the species of vertebræ do not separate. In the heart of the mountain on which stands the Castello di Jaci, there are large balls, from two to four feet in diameter, resembling in form the large pyrites in the chalk of Champagne. These balls of lava are formed of pyramidal columns, united by their points in a common centre.” *Catalogue des Laves de l'Etna*, page 453.

The division of the upper part of basaltic columns into several smaller ones, has also been observed in the basaltic columns of Fairhead, by Dr. RICHARDSON. See NICHOLSON'S Journal, 4to. Vol. V. page 321.

be such, are prismatic.* Columns of porphyry are not rare; and, among other places, are found near Dresden, several feet in length, and not more than two inches in diameter. Columns of petrosilex compose a large portion of a mountain near Conistone lake. Very perfect quadrangular prisms of argillaceous schistus are found near Llanwrst. Rubble slate assumes the columnar form at Barmouth. The limestone near Cyfartha, in Glamorganshire, is divided into very regular acute rhomboidal prisms: even the sandstone of the same district is not unfrequently columnar; and one of the beds of gypsum at Montmartre is distinctly divided into pretty regular columns. Sandstone, clay, argillaceous iron ore, and many other substances, become prismatic by torrefaction; and the prisms of starch formed in drying have often been considered as illustrative of basaltic formations.

I am very far from conceiving, that all these configurations are influenced by such systematic arrangements as have determined the form of some basaltic columns. I consider most of them as solely attributable to contraction; which is only a farther

* Almost all the prisms at the foot of Etna, described by *DOLOMIEU*, are of dubious origin; most of them are probably basalt. The columns of the *Vicentine* are of the same substance, and so are the prismatic lavas of *Auvergne*, and of the *Vivarais*. The bed of lava at *la Scala*, near *Portici*, is divided by vertical fissures, which give it the aspect of irregular columns. At *Aquapendente*, in a quarry of undoubted lava, near the road, are some much more perfect prisms; but the most beautiful I have seen, are the small ones from *Ponza*. The columns at *Bolsena*, are said to be basalt. Those of the *Euganean hills* are very irregular in form; in their texture they are certainly wholly unlike granite, which *Mr. STRANGE* thought they resembled. I believe them to be lava.

The mention of some columnar formations that follows, is by no means intended as an enumeration of them. I have confined myself to those which I have either inspected in their natural situation, or of which I have seen numerous specimens.

extension of the aggregative force, and must be regulated by the texture, the form, and the position of the mass. Where the texture of the mass is homogeneous, and its contractions uniform, its dimensions may be diminished, without its continuity being destroyed, provided its aggregation be so strong as to overcome the *vis inertiae* of the mass, and its adhesion to other substances. But, when the resistance is sufficient to overcome the aggregation, the mass will be rent by fissures perpendicular to the direction in which the greatest resistance to its contraction takes place, or, in other words, by fissures perpendicular to its greatest surface; for it is from the extremities of the greatest surface, that the largest quantity of matter must traverse the greatest space, in order that the contraction may be performed without breach of continuity; therefore, if it be an extensive tabular mass, it will be divided into prisms, by fissures perpendicular to its surfaces. The power of aggregation would determine these prisms to be hexagonal, as that form contains the greatest quantity of matter in the least surface, of any prisms that can be united without interposing prisms of other forms. But this would require the texture, the contraction, the thickness of the mass, and its adhesion to surrounding substances, to be every where precisely the same; and, as these conditions can never be fulfilled in an extensive formation, all the irregularities that are found must necessarily ensue. The same rule that determines the fissures of a tabular mass to be perpendicular to its surfaces, must determine the rents in a spheroid to be directed from its periphery to its centre.

Though these considerations may be sufficient to explain the tendency to division into prisms, which is so generally extended, and which has produced many of those abortions that have been

dignified with the name of columns, because they have occurred in lavas and in rocks of trap formation, they are utterly inadequate to illustrating the formation of the more perfect basaltic prisms: they offer no means of accounting for the extreme regularity of the sides and the precision of the angles, for the articulations, for the close contact in which the perfect columns are placed to one another, nor for their mutual adhesion, which is so strong, that it often requires considerable violence to separate them. These facts are in absolute contradiction to all idea of retreat or contraction, and seem to me to coincide perfectly with the explanation of their origin which I have already presumed to lay before you.

I have the honour to be, &c.

GREGORY WATT.